SECTION I
INTRODUCTION

I.1 BACKGROUND

Fuel cells are electrochemical devices that enable the chemical energy of fuels to be converted directly into electricity, thereby avoiding the fundamental loss of efficiency and emission of air pollutants associated with combustion-based engines. This prospect has motivated repeated attempts to develop fuel cells into practical power sources since discovery of the concept in 1839. The first success came 120 years later when fuel cells using ultrapure hydrogen fuel and oxygen became the new NASA power source that made manned space flight practical. This achievement encouraged large efforts, especially in the United States and Japan but also in other industrialized countries, over the past 30 years to develop fuel cells for terrestrial applications — efforts that are now beginning to pay off with emergence of a new generation of highly efficient, clean and versatile sources of electric power.

The potential for superior efficiency and zero or near-zero emissions has also long attracted interest to fuel cells as the automotive engine of the future. Indeed, the basic technical feasibility of a fuel cell to power an electric vehicle was shown more than 30 years ago. However, systematic efforts to realize the efficiency and emissions benefits of fuel cells in the transportation sector have materialized only in the last 10 years, long held back by the perception that fuel cells would be too expensive and their performance too low for use as automotive power sources. Motivated by concerns about urban air pollution, the pressures on resources by a rapidly growing world population, and global climate change caused by build-up of atmospheric carbon dioxide, these efforts have expanded into a large number of research, development and engineering programs in North America, Europe and Japan. Their overall goal is to develop a fuel cell electric engine that will give electric vehicles (EVs) the range of conventional cars while attaining environmental benefits comparable to those of battery-powered EVs.

The impressive advances made in many of these programs, and the increasing involvement of major automobile manufacturers with their extensive capabilities and resources now raise the prospect that fuel cell electric vehicles (FCEVs) might become a commercial reality in the next decade. Clearly, this possibility has important implications for the State of California and its Air Resources Board (ARB), the agency with regulatory responsibility for attainment of legislated air quality standards.

It is important to recognize, however, that the development of fuel cell electric engines and vehicles that can be fully competitive with internal combustion engine (ICE) vehicles in performance and cost faces a number of very difficult challenges. Fuel cell engine weight, volume and costs must be dramatically reduced from the levels typical for established fuel cell technologies. Equally important, efficient and reliable operation of fuel cell engines on logistically and economically feasible fuels under the wide range of conditions encountered in automobile propulsion must be achieved. Given the potentially large, positive environmental impact of FCEVs on the one hand and the current uncertainties and differences of opinion on their future competitiveness on the other, it is important for ARB to arrive at an independent judgment on the prospects of fuel cells as automotive power sources.

I.2 PURPOSE AND SCOPE

The purpose of this study, performed by the Fuel Cell Technical Advisory Panel for and on behalf of ARB, is to determine the current development status of automotive fuel cells, assess the capabilities, commitments and plans of the leading organizations in the field, and judge the prospects for cost-competitive fuel cells and FCEVs to become commercially available within the next 5-10 years.

Early in the study, the Panel decided to focus its investigation on the proton exchange membrane (PEM) fuel cell, the only one among established fuel cell types that combines operation near ambient temperature and on air with excellent prospects for high performance and long life. All the leading automotive fuel cell technology developers have selected versions of the PEM technology for their programs. Within the scope of that technology, the Panel obtained and examined information regarding the factors on which automotive fuel cell development schedule, achievable performance and ultimate cost are likely to depend most strongly: technology status of the fuel cell stack, components and the main subsystems including the fuel processor and major auxiliary components;

key issues in power plant and vehicle integration; and the choice of fuel with its implications for technology and infrastructure.

Information was solicited from a large number of organizations and individuals involved in fuel cell and fuel cell electric vehicle (FCEV) development. These included not only the large, comprehensive programs established during the last several years to develop, engineer and manufacture complete fuel cell engines and to integrate them into mass-produced vehicles, but also smaller and/or specialized developers of critically important components and subsystems. Important aspects of the Panel's investigation were to define the remaining technical and cost issues and to better understand the efforts and commitments leading developers are making to resolve them.

The Panel concentrated its investigation on PEM fuel cell and FCEV programs in North America, Europe, and Japan. Even within these regions, it was not possible to interact with every credible source of information. The Panel believes, however, that its efforts covered a group of organizations and programs sufficiently representative to make the conclusions reported here robust.

I.3 APPROACH

The Panel study proceeded through several stages:

1) Collection of information on automotive fuel cell technologies and issues. This was accomplished through written and personal contacts with individuals and organizations believed to be leaders in the development, engineering and manufacturing of PEM fuel cell system components, subsystems and complete systems.
2) Formulation and critical evaluation of the information collected and identification of knowledge gaps. In many cases, this step was followed by requesting, receiving and integrating supplementary information from the Panel's information sources.
3) Review of the Panel's draft findings with information sources to assure accuracy and avoid inadvertent publication of restricted information given to the Panel in confidence.
4) Development of the Panel's conclusions from its findings, making sure that these conclusions represented a consensus and were compatible with the charter and scope of the Panel' study.
5) Preparation of this final report which summarizes the Panel's major findings and conclusions. To put them in perspective, this report includes a description of fuel cell

principles and a discussion of the practical challenges for automotive fuel cell engine development.

An important part of the Panel's approach was the development and use of a detailed questionnaire on fuel cell stack, subsystem and system performance; prospective costs; and likely choices of fuels. Additional questions addressed the capabilities, resources and plans of organizations active in the development of automotive fuel cells. This questionnaire is reproduced as Appendix A; a listing of the organizations contacted for information is given in Appendix B. Questionnaire recipients were encouraged to focus their responses on what they considered to be their own areas of fuel cell expertise and involvement.

Because the automotive fuel cell field is advancing rapidly — in technology as well as in commitment of resources and formation of alliances for fuel cell development and commercialization — the Panel followed the questionnaire with visits to as many leading organizations as practical (see Appendix B). Individual Panel members also participated in a number of important technical meetings and fuel cell conferences, and they solicited information from the main government-funded fuel cell development programs in the United States, Europe and Japan. The entire Panel critically reviewed the information collected and developed the main conclusions and recommendations in a workshop, drawing on the members' diverse fuel cell expertise and knowledge bases.

This report presents the findings and collective judgment of the Panel. Section II provides the background discussion of fuel cell principles, technologies and the practical requirements that must be met by fuel cell engines intended for automobile propulsion. Findings are reported in Section III, and the Panel's conclusions are summarized in Section IV.